Deliverable Phase 1 – Climate risk assessment

Risk and Vulnerability Assessment in Municipality of Rafina-Pikermi (RAFRVA)

Greece, Attica/Municipality of Rafina-Pikermi

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• Document Information

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Abbreviations and acronyms

Abbreviation / acronym	Description
RAFRVA	Risk and Vulnerability Assessment in Municipality of Rafina-Pikermi
SLR	Sea-level rise
EAD	Estimated Annual Damage
CRA	Climate Risk Assessment
MSL	Mean Sea Level

Executive summary

This deliverable presents the results of Phase 1 of the RAFRVA project—*Risk and Vulnerability Assessment in the Municipality of Rafina-Pikermi*—conducted under the Horizon Europe CLIMAAX programme. The aim of this phase is to establish a scientifically rigorous, harmonised Climate Risk Assessment (CRA) tailored to the local context of Rafina-Pikermi, a coastal municipality in Eastern Attica, Greece, which faces escalating exposure to climate-induced hazards. The main focus of this assessment lies on two climate-related threats: (i) heatwaves and (ii) river and coastal flooding.

This deliverable was developed to address urgent needs for locally relevant, data-informed adaptation planning in a municipality known for its vulnerability to both meteorological and hydrological extremes. The reader will gain a complete picture of the municipality's current climate risk profile, the methodological steps taken for risk quantification, and the basis upon which targeted adaptation and resilience actions will be developed in subsequent phases. The contractor METEOME led the technical implementation of hazard and risk workflows, applying the CLIMAAX Handbook and toolbox, including downscaled Euro-CORDEX projections, EU-wide hazard layers, and local datasets wherever available. The CLIMAAX Regional Adaptation Support Tool (RAST) provided the overarching structure for the assessment, ensuring compliance with EU adaptation planning best practices. The key findings on the studied hazards are summarised as follows:

- Heatwaves are projected to increase markedly under both RCP4.5 and RCP8.5 scenarios. By 2050, the number of heatwave days may rise to 17–18 days under RCP4.5 and to 23–24 under RCP8.5. The inland urban core exhibits high vulnerability due to overlapping exposure (high land surface temperatures >45°C), sensitive populations (elderly, children), and limited cooling infrastructure. The port area, which hosts millions of annual passengers, also faces elevated exposure.
- River flooding, especially flash floods in the Megalo Rema basin, represents a historically significant hazard. However, the current CLIMAAX workflows—based on global DEMs and riverine flood typologies—failed to replicate observed flood behavior, leading to a critical underestimation of risk. Flash flood characteristics, such as short lead times and debris flows, were not captured. As a result, modeled inundation, damage estimates, and population exposure are inconsistent with documented past events.
- Coastal flooding presents a localized but credible risk, especially under sea level rise scenarios. Low-lying zones around the Rafina port face increased inundation depths (up to 1 m by 2050), with potential disruptions to municipal car parks, critical access routes, and port operations. Unlike the river flood outputs, coastal flood modeling aligned more closely with local observations.

Main actions undertaken include stakeholder mapping, hazard screening, workflow selection and execution, scenario definition (RCP4.5 and RCP8.5 up to 2050), and the generation of preliminary risk maps and exposure overlays using the CLIMAAX toolbox. Contributions to the overall CLIMAAX project include the operationalisation of the methodological framework in a high-vulnerability, data-scarce setting, identification of workflow limitations, and the establishment of baseline risk metrics that will inform future adaptation planning, civil protection updates, and regional policy alignment.

Conclusions: This phase confirms that heatwaves represent an intensifying and well-characterized threat, warranting immediate local adaptation actions (early warnings, passive cooling strategies, vulnerable group protection). Coastal flooding is also a credible hazard requiring localized mitigation. In contrast, river flood risk remains critically underestimated and calls for urgent methodological refinement, including integration of pluvial and flash flood modeling and the use of locally calibrated topographic and exposure data. Stakeholder feedback confirms the need for stronger local participation and higher data granularity in the next phase. The RAFRVA lays a strong foundation for evidence-based resilience planning in Rafina-Pikermi.

● Introduction

●.1 Background

The Municipality of Rafina-Pikermi is a coastal urban region situated in Eastern Attica, Greece, approximately 30 kilometers east of Athens. The municipality encompasses an area of 40.501 km², with a population of approximately 22,327 residents. Known for its proximity to the historical Marathon city and the scenic slopes of Mount Penteli, Rafina-Pikermi hosts the second busiest port in Attica, which annually facilitates travel for about two million passengers. The municipality is marked by a vibrant mix of densely populated urban areas and substantial ecological zones, including valuable riverbeds and coastal ecosystems. These natural features enhance the region's environmental significance but simultaneously increase its susceptibility to climate-related hazards.

Over recent years, the municipality has faced escalating climate risks, notably highlighted by severe events such as the devastating wildfires of July 2018, commonly referred to as the "Mati fire tragedy", which tragically claimed more than 100 lives. This catastrophic event was intensified by gale-force western winds and prolonged drought conditions. Furthermore, Rafina-Pikermi has experienced multiple severe hydrometeorological events, including flash floods and intense storms. Examples of these include the Medicane "Xenophon/Zorbas" in September 2018, with wind gusts reaching up to 83 km/h, and Storm "Genesis" in June 2022, which led to significant flooding. The frequency, duration, and intensity of droughts and extreme precipitation events have notably increased over the past decades, exacerbating the existing vulnerability of the region.

The local infrastructure is currently challenged by an aging and inadequate water management system, insufficient drainage networks, and the legacy impacts of inadequate spatial planning and land management practices. The economic impacts of the Greek financial crisis further constrained the municipality's resources, limiting effective emergency preparedness and adaptation strategies. Thus, the Rafina-Pikermi community is in urgent need of a comprehensive climate adaptation framework to enhance its resilience and safeguard its population, infrastructure, and ecological assets.

●.2 Main objectives of the project

- *Describe the objectives and significance of the project to the region or community*
- *Include the expected benefits of applying the CLIMAAX Handbook*

The primary objectives of the RAFRVA Project are centered around conducting a detailed, transparent, and harmonized climate risk assessment specifically tailored to the municipality's unique geographical, ecological, and socio-economic context. Utilizing the CLIMAAX Handbook, the project aims to identify and quantify key hazards such as extreme heat events and floods, as well as associated exposures and vulnerabilities at the local level.

A critical goal of RAFRVA is to provide a robust scientific foundation and methodology that supports informed decision-making for local climate adaptation policies. Through the application of the CLIMAAX methodological framework and risk assessment tools, Rafina-Pikermi will be empowered to establish clear priorities and actionable strategies to mitigate and adapt to climate risks.

Moreover, the project seeks to align the municipality's planning and governance processes with the best practices outlined in the CLIMAAX Handbook and broader EU climate resilience initiatives.

The expected benefits of adopting the CLIMAAX Handbook within this project are numerous. It will:

- facilitate risk-informed governance,
- enhance the effectiveness of targeted adaptation measures, and
- improve local emergency response planning.

Additionally, the increased transparency and involvement of stakeholders will lead to greater community awareness, strengthening public support for climate resilience measures. Overall, the outcomes of RAFRVA will significantly contribute to safeguarding the local economy, enhancing public safety, preserving ecological integrity, and ultimately fostering a resilient and sustainable future for the Rafina-Pikermi community.

●.3 Project team

The RAFRVA is coordinated and led by the Municipality of Rafina-Pikermi in collaboration with the environmental analytics and services company, METEOME. METEOME is specifically responsible for conducting climate hazard analyses, implementing risk assessment workflows, and ensuring rigorous scientific application of the CLIMAAX framework.

The project team involves close cooperation with municipal departments integral to climate risk management and urban development, notably civil protection and urban planning departments. Their local insights and sector-specific expertise are instrumental in accurately defining and evaluating the regional climate risks and implementing appropriate adaptation strategies.

In addition, the project emphasizes active stakeholder engagement, capturing input and feedback from a diverse range of local actors. This comprehensive engagement ensures that the outcomes of the RAFRVA are locally relevant, broadly supported, and effectively integrated into the municipality's long-term adaptation and resilience strategies.

●.4 Outline of the document's structure

- Section 2 presents the scoping process, selection of workflows, and preliminary risk analysis for heatwaves and river/coastal floods.

- Section 3 summarizes the conclusions of Phase 1 and key takeaways.

- Section 4 evaluates progress and outlines the contribution to the next phases.

- Section 5 provides an overview of supporting outputs.

- Section 6 lists references used in the assessment.

● Climate risk assessment – phase 1

●.1 Scoping

●.1.1 Objectives

The primary objective of the Risk and Vulnerability Assessment (RVA) for the Municipality of Rafina-Pikermi (RAFRVA) is to provide a detailed, structured, and transparent understanding of the climate risks facing the municipality, focusing particularly on heatwaves, and river and coastal flooding. The RVA seeks to inform and facilitate targeted climate adaptation strategies, enhance local emergency planning capabilities, and support effective policymaking. It aims to identify the sectors and population groups most vulnerable to these climate-related risks, guiding prioritization and resource allocation for adaptation measures.

The outcomes of this assessment will feed directly into municipal climate adaptation policies, the updating of local civil protection plans, and emergency preparedness initiatives. It will also contribute to wider regional and national strategic adaptation planning frameworks.

Limitations of this climate risk assessment include:

- data availability constraints related to gaps in historical local weather/climate observations for a long period (e.g., detailed weather data from ground weather stations exist only after 2012),
- data gaps for certain vulnerability indicators and limited availability of high-resolution socio-economic projections.

Stakeholder participation at this stage has been primarily institutional, with plans for broader engagement in future phases.

●.1.2 Context

Historically, the Municipality of Rafina-Pikermi, situated within Eastern Attica, has increasingly faced significant climate hazards, including severe flooding along the Rafina stream (Megalo Rema), persistent heatwaves, and destructive wildfires. Past incidents such as the catastrophic Mati wildfire in 2018 (less than 2 km north from the northern municipality borders), intensified by drought and strong winds, resulting in over 100 fatalities, have underscored significant gaps in emergency preparedness, spatial planning, and forest management. Despite previous recognition of these threats, assessments and management of climate risks in the region have been largely reactive and fragmented due to limited resources and inadequate integration of climate change considerations into local planning processes.

The Rafina-Pikermi RVA project aims to systematically address these growing climate vulnerabilities by implementing a structured, harmonized approach aligned with the broader European Union and national strategies for climate resilience. The key problem being addressed is the increasing vulnerability and exposure of Rafina-Pikermi to climatic extremes—particularly floods and heatwaves—due to the combination of climate change impacts, inadequate spatial planning, aging infrastructure, and limited financial resources.

Within a wider regional and national development context, Rafina-Pikermi's vulnerabilities are reflective of broader challenges faced by Greek municipalities, including economic constraints stemming from the prolonged Greek financial crisis. This crisis has hindered necessary infrastructural investments and reduced the capacity for proactive climate risk management. Furthermore, urban expansion and inadequate land-use management have increased environmental pressures, exacerbating the severity of impacts from extreme climate events.

The governance context of Rafina-Pikermi is shaped by national policies and frameworks, including Greece's National Adaptation Strategy and the EU Mission on Adaptation to Climate Change. Local regulations, such as spatial and urban planning laws, civil protection guidelines, and environmental management policies, provide an operational context for integrating climate risk assessments into broader municipal governance structures.

Relevant sectors in Rafina-Pikermi include urban infrastructure, public health, transportation (especially port infrastructure critical for tourism and commerce), environmental management, agriculture, and local economies dependent on tourism and fishing. These sectors face varying but substantial risks from climate change impacts, such as increased heat stress affecting human health, flooding disrupting transportation and infrastructure, as well as threats to ecological and residential zones, and adverse economic impacts from tourism disruption.

External influences affecting Rafina-Pikermi's vulnerability include regional initiatives such as broader Attica climate resilience planning, national disaster risk reduction strategies, and EU-funded projects designed to enhance climate adaptation and sustainability. Collaboration with these external initiatives can provide beneficial synergy, data sharing, and resource optimization.

Possible adaptation interventions identified include the development and implementation of comprehensive early warning and emergency response systems, investment in cooling infrastructure and passive cooling solutions for buildings, improvement and expansion of drainage networks, sustainable floodplain management, integrated spatial and risk management planning, and extensive community education and awareness programs. These adaptation measures aim to significantly enhance Rafina-Pikermi's resilience to future climate impacts, aligning local actions with broader regional and national adaptation goals.

●.1.3 Participation and risk ownership

The initial steps towards stakeholder involvement began with consultations targeting municipal departments essential to climate adaptation planning, including urban planning, civil protection units, and technical infrastructure services. These initial engagements have established the groundwork for a structured stakeholder management strategy, ensuring clarity of roles, responsibilities, and communication channels.

Relevant stakeholders identified various levels of governance and societal representation, including regional government authorities, civil protection agencies, and sector-specific municipal departments such as infrastructure and environmental management. Non-governmental organizations active in environmental protection, climate advocacy, and local development have been identified as crucial partners in facilitating community engagement and awareness.

Representatives of vulnerable and priority groups, including elderly residents, economically disadvantaged residents, and communities residing in coastal areas particularly exposed to flooding risks, have been prioritized for targeted consultations. Additionally, stakeholders such as local business owners (especially SMEs), urban planners, engineers, the Port Authority, emergency services (including firefighters and emergency action agencies like the national 112 service), and representatives from academia and schools have been recognized as key contributors due to their roles in urban functionality, education, and community mobilization.

Risk ownership is regulated through clearly defined responsibilities within the municipal governance structure, with the local Civil Protection Authority playing the central coordinating role. This coordination is supported by cross-departmental collaboration frameworks, facilitating integrated responses and proactive risk management strategies. Risk ownership mechanisms are formalized within the Municipality's Civil Protection Plan, which is undergoing updates to incorporate new climate risks identified through this assessment process.

The community's acceptable level of risk will be evaluated and reassessed through stakeholder dialogues, structured consultations, and periodic reviews of municipal policies and community surveys. This approach ensures that local perceptions, societal values, and risk tolerance levels inform the adaptive measures and strategies deployed.

Communication of the RVA findings and outcomes will be strategically conducted through diverse channels tailored to the stakeholder profiles. These include structured technical reports for governmental and expert stakeholders, digital media and municipal websites for broader community engagement, and targeted participatory workshops aimed at vulnerable groups and sectors directly impacted by identified risks. Educational initiatives in collaboration with local schools and academia could be considered to enhance awareness, preparedness, and resilience-building across community levels, fostering a participatory and inclusive approach to climate adaptation.

●.2 Risk Exploration

●.2.1 Screen risks (selection of main hazards)

The Municipality of Rafina-Pikermi is particularly vulnerable to several climate-related hazards. Based on an extensive review of local climate data, historical incidents, and expert consultations, the following hazards have been identified as especially significant:

Heatwaves: Heatwaves are becoming increasingly frequent and severe, significantly affecting public health, especially among elderly populations and residents living in densely urbanized areas. Heatwaves in Greece have been studied by Galanaki et al. (2023) who found an increasing frequency, intensity, and duration from 1950 to 2020, especially pronounced after 1990. In Attica specifically, including the Rafina-Pikermi area, heatwaves are frequent, intense, and of notable duration, making it one of the main heatwave hotspots in Greece. Additionally, Attica experiences a significant increase in days with extreme heat stress conditions, which are intensified by urban characteristics and high population density, leading to substantial socio-economic impacts and health risks. The urban heat island effect exacerbates these conditions, intensifying heat stress on individuals and overburdening healthcare and social support systems. Prolonged heat events negatively impact productivity, strain energy and water resources, and deteriorate living conditions, particularly in the more populated and infrastructure-dense areas of Rafina-Pikermi.

River and Coastal Flooding: Rafina-Pikermi faces notable vulnerabilities associated with river and coastal flooding due to intense rainfall events and rising sea levels. Historically, the Megalo Rema, a crucial natural watercourse in Rafina, has experienced several severe flooding incidents (e.g., 2 November 1977; 26 March 1988; 22 February 2013; November 2016; June 2022; November 2024; and 3 February, 2025). Anthropogenic interventions, urban expansion, and inadequate flood management practices have compounded these vulnerabilities, resulting in substantial damage to residential properties and critical infrastructure. Recent incidents during flood control construction works have further highlighted deficiencies in current flood management strategies. Local communities and environmental organizations have increasingly advocated for integrated and sustainable flood management practices that combine infrastructure improvements with ecological preservation.

Data and Knowledge Sources: For hazard identification and risk screening, multiple data sources were utilized, including the High Impact Weather Events database developed by the METEO Unit at the National Observatory of Athens, METEOME hazard simulations, and Copernicus datasets. Historical climate data and local weather observations provided detailed records of hazard occurrences, while available socio-economic vulnerability profiles helped highlight populations at greatest risk. Nonetheless, further detailed information and high-resolution data are required, including comprehensive socio-economic vulnerability assessments, improved projections of climate change impacts at the municipal level, and detailed evaluations of existing infrastructure resilience. These data enhancements will support more refined and effective risk analysis and adaptation planning in subsequent project phases.

Selected Hazards for Assessment: Based on the above, the climate risk assessment will specifically focus on two primary hazards:

- Heatwaves
- River and coastal floods

The assessment aims to evaluate these hazards comprehensively, considering their current and projected future impacts, and informing targeted strategies for improved resilience and adaptive capacity within the Municipality of Rafina-Pikermi.

●.2.2 Workflow selection

The selected workflows for this CRA are:

●.2.2.1 **Workflow #1**: Heatwaves

The risk workflow for heatwaves includes:

(a) Scoping: define clear objectives based on the local context of Rafina-Pikermi and establish boundaries for the analysis, specifically temporal (up to 2050), spatial (Municipality of Rafina-Pikermi), and hazard definition (EuroHEAT methodology).

(b) Hazard analysis: Utilize climate hazard data and scenarios available from the CLIMAAX Handbook, particularly high-resolution temperature projections (EURO-CORDEX datasets) for RCP 4.5 and RCP 8.5, and apply EuroHEAT definitions to identify heatwave episodes, focusing on both daytime and nighttime temperature extremes during June–August. Calculate frequency, intensity, and duration indices of heatwave days based on future projections.

(c) Exposure and Vulnerability assessment: Identify critical exposure areas using population density, land use data, and key vulnerable groups (i.e, elderly, disadvantaged populations).

(d) Risk evaluation: Synthesize hazard, exposure, and vulnerability information to prioritize high-risk areas and populations for targeted adaptation and emergency response.

For the heatwave risk, the following vulnerable groups are identified:
(a) elderly and people with chronic illnesses who present a heightened risk of heat-related health issues due to compromised physiological resilience;
(b) low-income residents with limited access to air conditioning or adequate cooling infrastructure, increasing vulnerability;
(c) urban populations who reside in the urban areas of Rafina with limited green infrastructure which exacerbates the urban heat island effect;
(d) travelers and tourists with increased vulnerability during transit and exposure in areas around the port of Rafina;
(e) school children who are exposed in school environments lacking adequate cooling facilities or green infrastructure.
For the analysis performed in this phase of the CRA we will focus the discussion on the available datasets of vulnerability and exposure available in CLIMAAX CRA Handbook.

●.2.2.2 **Workflow #2**: River and Coastal Floods

The risk workflow for river and coastal floods include: (a) risk identification: mapping of historical flooding events, climate data analysis on precipitation patterns, and sea-level rise projections; (b) risk analysis based on precipitation intensity, and sea-level scenarios; (c) risk assessment based on assessing population exposure, and potential impacts, with a particular focus on areas adjacent to riverbeds and coastal zones.

For the River and Coastal Floods risk, the following vulnerable groups and exposed areas are identified:
(a) residents near Megalo Rema and coastal neighborhoods who are directly exposed to flooding risks exacerbated by urban development and historically inadequate flood management practices;
(b) local businesses and SMEs (i.e., fuel stations) who are exposed to economic disruption due to infrastructure damage and interruption of commercial activities;
(c) public infrastructure, which is considered as critical infrastructure such as roads and public buildings facing increased flood exposure.

Through these risk workflows, the RAFRVA aims to generate a thorough understanding of the vulnerabilities and exposures specific to heatwaves and flooding within Rafina-Pikermi Municipality. The findings will significantly contribute to shaping targeted local adaptation and resilience strategies, strengthening community safety, preserving ecological assets, and ensuring sustainable urban and economic development.

●.2.3 Choose Scenario

The scenarios applied include near-term (2030) and mid-term (2050) projections under RCP4.5 (moderate emissions scenario) and RCP8.5 (high emissions scenario). These consider temperature and rainfall trends, sea-level rise projections, and socio-economic factors such as population growth in the Municipality.

●.3 Risk Analysis

●.3.1 Workflow #1- Heatwaves

Table 2-1 Data overview workflow #1

Hazard data	*Vulnerability data*	*Exposure data*	*Risk output*
EuroHEAT	WorldPop	Landsat8 satellite	10x10 risk matrix
	High Resolution Population Density Maps + Demographic Estimates		

●.3.1.1 Hazard assessment

The primary objective of this climate hazard assessment is to comprehensively evaluate the evolving threat posed by heatwaves in the Municipality of Rafina-Pikermi, leveraging high-resolution climate projections extending up to the year 2050. This detailed assessment employs the EuroHEAT methodology, an EU-wide standard that defines heatwaves based on significant health-related thresholds. Specifically, the method considers both daytime and nighttime temperature extremes, ensuring a holistic analysis of thermal stress experienced by the population during the warmest months of the year (June through August).

The assessment aims to deliver a structured and data-driven understanding of anticipated changes in the frequency, duration, and intensity of heatwave days under two distinct climate scenarios:

- RCP 4.5, representing a moderate emissions pathway where mitigation efforts significantly curb greenhouse gas emissions.
- RCP 8.5, which reflects a high emissions scenario corresponding to a business-as-usual trajectory with limited intervention measures.

By clearly identifying and comparing the projected trends and differences across these scenarios, this assessment aims to support the development of targeted, evidence-based adaptation strategies. Additionally, the insights derived will enhance local emergency preparedness measures and provide crucial guidance for municipal policy decisions. Ultimately, the goal is to effectively respond to and mitigate the growing public health challenges and infrastructure risks associated with extreme heat events, thereby improving community resilience and safeguarding the well-being of residents.

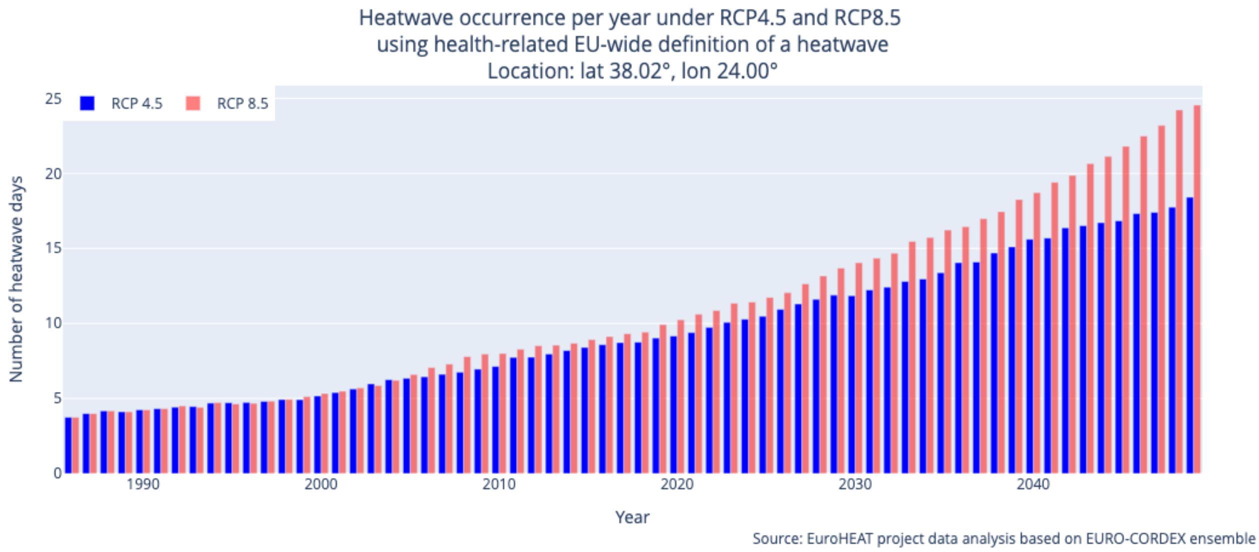

Fig. 2-1 Projected Evolution of Heatwave Days in Rafina-Pikermi up to 2050 based on the EuroHEAT project data

Figure 2-1 presents the projected number of annual heatwave days in Rafina-Pikermi, Greece, using the health-related EU-wide heatwave definition. This definition classifies a heatwave day as one on which both daytime (Tmax) and nighttime (Tmin) temperatures exceed their respective 90th percentile thresholds for at least two consecutive days between June and August. The main findings based on Figure 2-1 are summarised below:

- Increase of annual heatwave days under both scenarios: Historically, the municipality experienced approximately 4–5 heatwave days per year during the last decades of the 20th century. Projections indicate a consistent upward trend in heatwave frequency across both climate scenarios considered:
    - By 2050, heatwave occurrences are projected to increase substantially to around 17–18 days per year under the moderate emissions scenario (RCP 4.5).
    - Under the high-emissions scenario (RCP 8.5), projections suggest a further increase to approximately 23–24 days per year.
- Mid-Century Divergence Between Scenarios: Initially, both RCP scenarios show comparable trends up until the early 2020s. However, a marked divergence becomes increasingly apparent after 2030. The higher-emission scenario (RCP 8.5) distinctly accelerates the heatwave frequency compared to RCP 4.5, illustrating significant implications and elevated risk levels associated with continuing current emissions trajectories without mitigation.
- Nonlinear Increase Under RCP 8.5: The increase of heatwave days under RCP 8.5 scenario intensifies notably from 2030 onward, indicating accelerated increases and rising risks of compounded heat stress events. This underscores the urgent need for effective climate mitigation and adaptive strategies to prevent severe health, ecosystems and infrastructure consequences.

Overall, the analysis underscores that immediate and effective climate action can substantially mitigate future heatwave risks. The lower heatwave frequency projected under RCP 4.5, especially post-2030, clearly demonstrates the significant benefit and reduced health risk achievable through proactive climate intervention measures.

●.3.1.2 Risk assessment

This analysis incorporates Landsat8 satellite land surface temperature (LST), population data, and vulnerability indicators to map hazard, exposure, and vulnerability, and combines them into a spatial risk assessment map.

The western inland areas of the municipality show High to Very High LST values, indicating intense heat accumulation (Fig. 2-2). As seen in the LST time-series graph in Fig. 2-3, peaks exceed 45 °C, especially during early August, confirming extreme heat conditions even within a short monitoring window (summers 2021-2024). The eastern coastal area appears less exposed, possibly due to the vicinity to the sea and sea breeze effects.

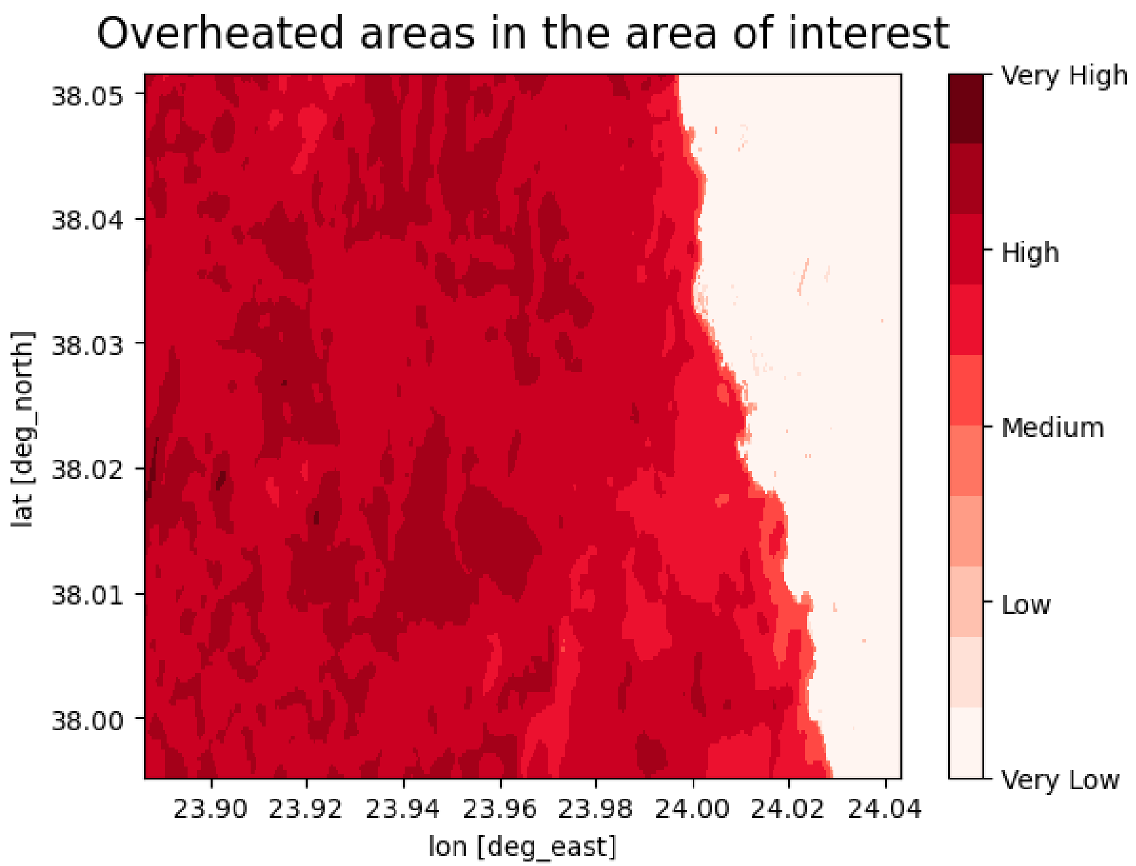

Fig. 2-2 Classification of Land Surface Temperature (LST) values into 10 groups: Very low [< 20-25°C], Low [25-35 °C], Medium [35-45 °C], High [45-55 °C], Very High [>55-60°C].

The time-series of LST mean values (Fig. 2-3) from 2021 to 2024 (days with cloud coverage <50% and with a NDVI-based emissivity) show consistently high summer land surface temperatures, with peaks over 40 °C, especially during July–August of each year. This confirms that Rafina-Pikermi is subject to repeated and intense heat episodes, likely to worsen under climate change.

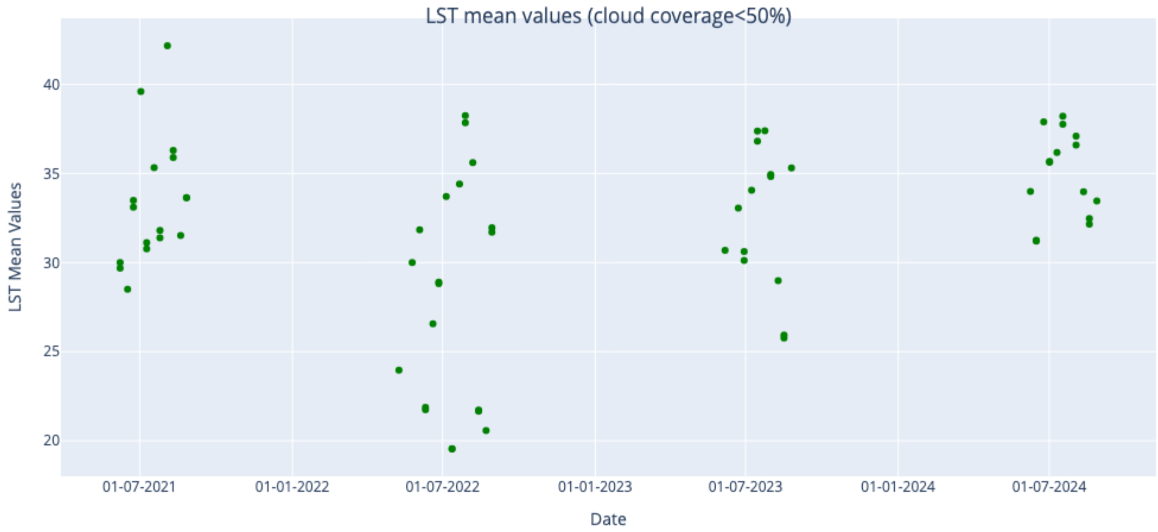

Fig. 2-3 Land surface temperature mean values for the Municipality Rafina-Pikermi, per Landsat8 image. Only the days corresponding to the LST pictures with cloud coverage lower than 50% are plotted.

Figure 2-4 presents the most overheated areas and the vulnerability level as defined from the population density in the Municipality Rafina-Pikermi. Much of the built-up inland region overlaps with High to Very High overheated zones, indicating areas where urban infrastructure and residents are directly exposed to extreme temperatures. The coastal edge shows Medium to Low exposure. The vulnerability map indicated that it exists in the eastern-central part of the Municipality, a pocket where population density is higher, which is flagged as of Very High vulnerability. Scattered medium-density residential areas in the central part of the municipality show Medium to High vulnerability. Coastal and sparsely populated inland zones remain Low to Very Low in terms of vulnerability.

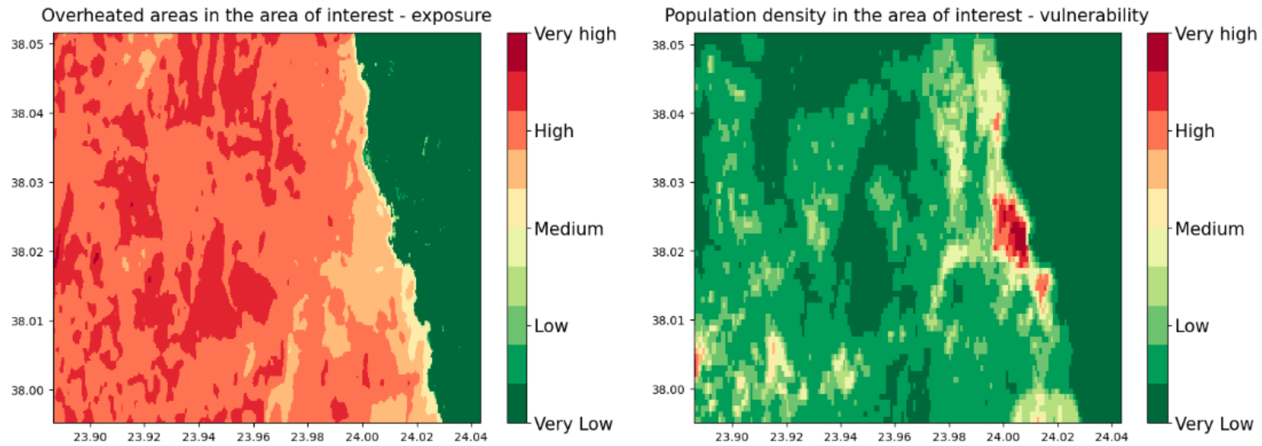

Fig. 2-4 The most overheated areas together with the population density of the vulnerable groups of the population (ages 0-5 and 65-90).

Using the risk matrix methodology shown in Fig. 2-5 that combines exposure and vulnerability, we have calculated the heat risk level provided in Fig. 2-6. The following conclusions are drawn:

- Highest Risk Zones are found in the eastern part of Rafina-Pikermi, where hot areas coincide with dense and vulnerable populations.
- Medium to High Risk Areas are widespread across the western interior.

Risk matrix 10+10

Heat exposed areas based on the LST	1	2	3	4	5	6	7	8	9	10
10	Medium 11	Medium 12	High 13	High 14	High 15	High 16	Very high 17	Very high 18	Very high 19	Very high 20
9	Medium 10	Medium 11	Medium 12	High 13	High 14	High 15	High 16	Very high 17	Very high 18	Very high 19
8	Medium 9	Medium 10	Medium 11	Medium 12	High 13	High 14	High 15	High 16	Very high 17	Very high 18
7	Low8	Medium 9	Medium 10	Medium 11	Medium 12	High 13	High 14	High 15	High 16	Very high 17
6	Low 7	Low8	Medium 9	Medium 10	Medium 11	Medium 12	High 13	High 14	High 15	High 16
5	Low 6	Low 7	Low8	Medium 9	Medium 10	Medium 11	Medium 12	High 13	High 14	High 15
4	Low 5	Low 6	Low 7	Low8	Medium 9	Medium 10	Medium 11	Medium 12	High 13	High 14
3	Very low 4	Low 5	Low 6	Low 7	Low8	Medium 9	Medium 10	Medium 11	Medium 12	High 13
2	Very low3	Very low 4	Low 5	Low 6	Low 7	Low8	Medium 9	Medium 10	Medium 11	Medium 12
1	Very low 2	Very low 3	Very low 4	Low 5	Low 6	Low 7	Low8	Medium 9	Medium 10	Medium 11

Vulnerable population density

Fig. 2-5 Vulnerability vs Heat Exposure based on LST.

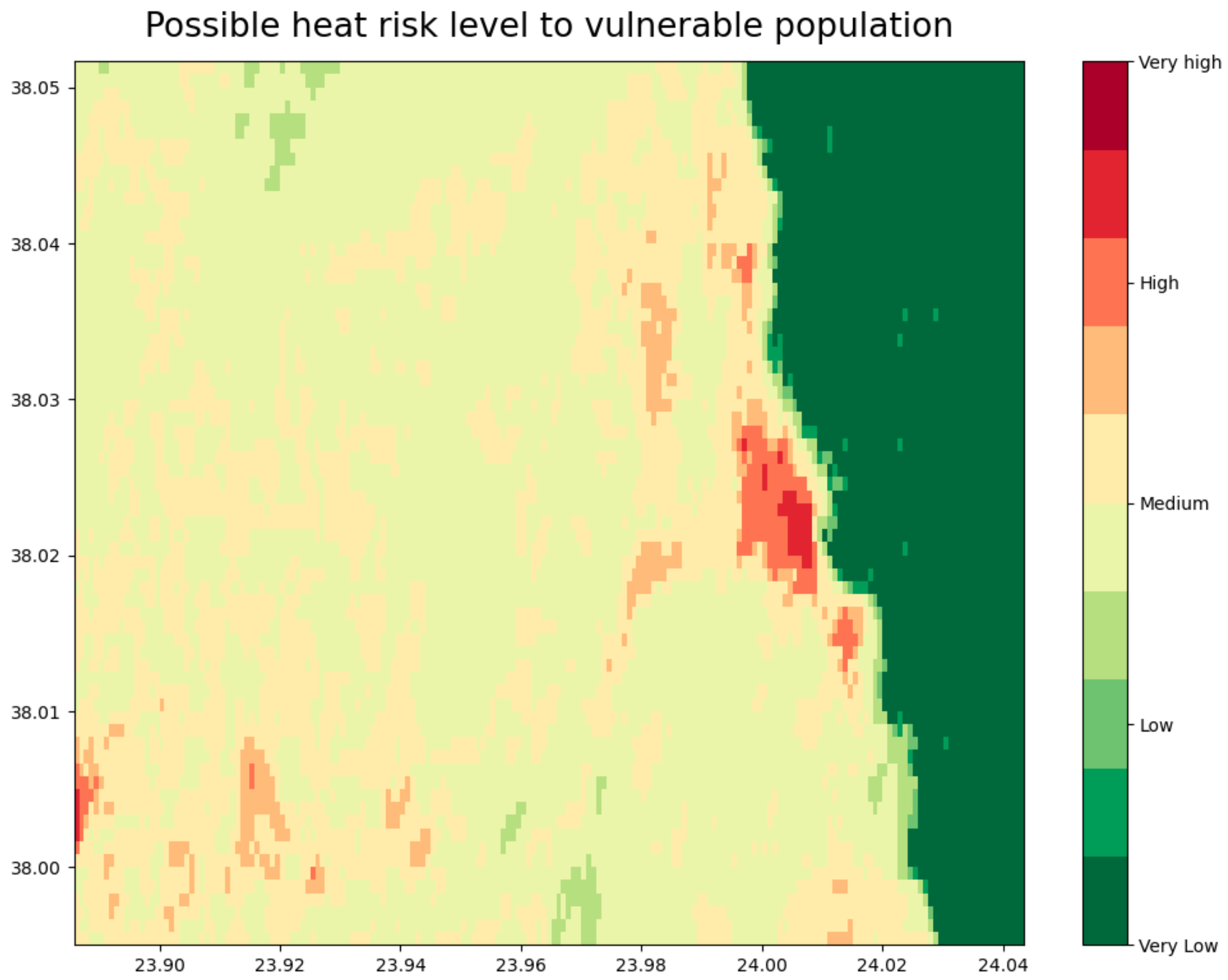

Fig. 2-6 Possible heat risk level to vulnerable population, derived by multiplying the exposure by vulnerability and using the Risk Matrix in Figure 2-5.

•.3.2 Workflow #2 - River and Coastal Floods

Table 2-2 Data overview workflow #2

Hazard data	*Vulnerability data*	*Exposure data*	*Risk output*
Global Tide and Surge Model results (GTSMv3.0)		Digital Elevation model SRTM	Coastal flood risk
JRC's high-resolution flood maps (present)	LUISA Land cover	Population GHS-POP R2023A dataset	Flood and population risk maps
Aqueduct Floods coarse-resolution flood maps (future)		OpenStreetMap Building data	Building damage risk maps Population displacement risk Critical infrastructure exposed

•.3.2.1 Hazard assessment

•.3.2.2 River floods

The analysis followed the standardized methodology provided in the CLIMAAX Handbook for River Flooding and Coastal Flooding, employing the workflows for hazard identification, risk calculation, and land cover exposure. The primary objective was to characterize river and coastal flood hazard across a range of present and future climate scenarios and to estimate economic damages under different return periods.

Despite the use of established modeling tools and workflows, the generated outputs failed to reflect known historical flood behavior in the study area. Notably, the river flood threat posed by the Megalo Rema stream, which has a documented history of flash floods including the severe 2013 event, was not captured in the model results.

The methodology was based on the CLIMAAX workflows, which make use of pre-calculated flood hazard datasets from JRC Global Flood Maps and Aqueduct Floods, including both riverine and coastal flood scenarios. Present-day river flood hazard was assessed using return periods of 10, 50, and 100 years, while future climate scenarios were analyzed for RCP4.5 and RCP8.5 pathways, focusing on the years 2030, 2050, and 2080 for 1-in-250 year events. Coastal flood scenarios were evaluated for 2018 and 2050, using extreme sea level data under different return periods (1-in-2, 10, 100, and 250 years). The LUISA land cover dataset was used for exposure assessment.

Hazard outputs were overlaid with municipal boundaries and spatial extents of historical flooding to validate the performance of the models.

The JRC flood maps for present-day river flood hazard (ca. 2018) reveal extremely limited inundation, confined to very small areas near the coastline, even under a 1-in-100 year return period, and not at the Megalo Rema stream (Fig. 3-1). The Megalo Rema riverbed, which historically channels intense runoff during storms, is shown with no flood extent in any return period. The modeled inundation depths within the Rafina-Pikermi municipality do not exceed 0.6 meters in most cases and are highly localized.

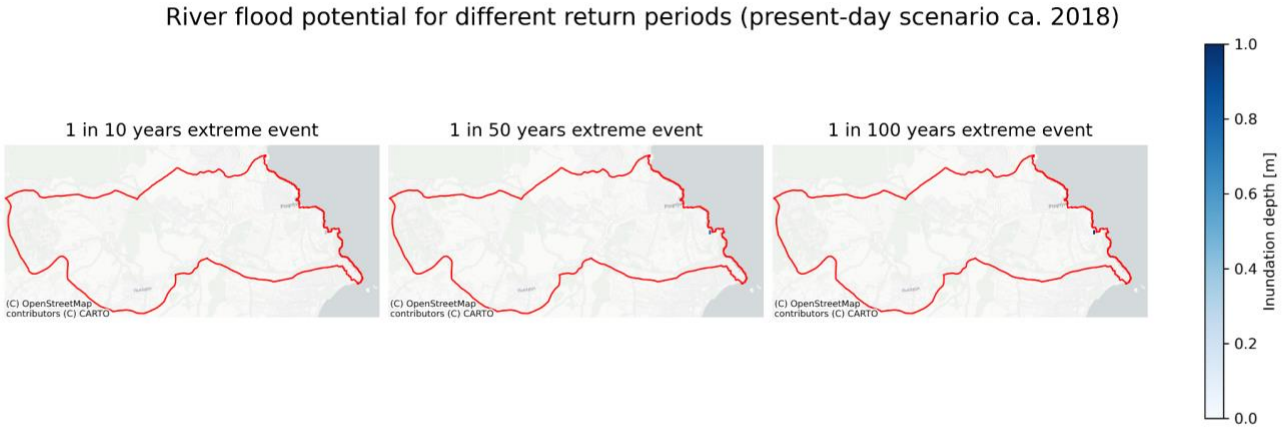

Fig. 3-1 River flood potential depth (m) for return period= 10, 50, and 100 years in the present climate (ca.2018).

For future river flood projections under both RCP4.5 (Fig.3-2) and RCP8.5 (Fig. 3-3) (up to 2080), the hazard maps continue to show minimal expansion of flood-prone zones. Inundation is concentrated in a narrow corridor at the river mouth, with maximum depths still under 0.4 meters, and negligible differences compared to the 1980 baseline.

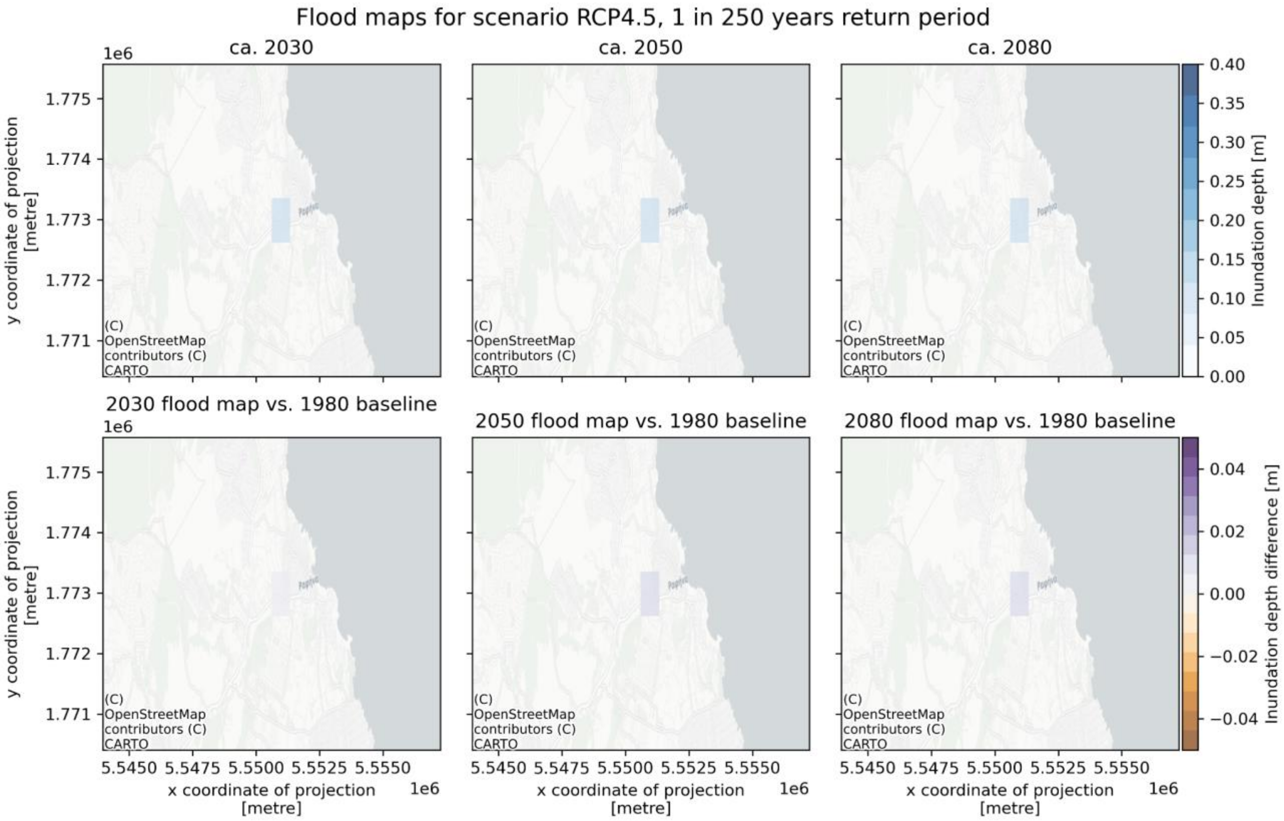

Fig. 3-2 Inundation depth (m) for climate scenario RCP4.5 for an event with a return period 250 years in 2030, 2050 and 2080 (upper row) and inundation depth difference (m) with respect to 1980 baseline.

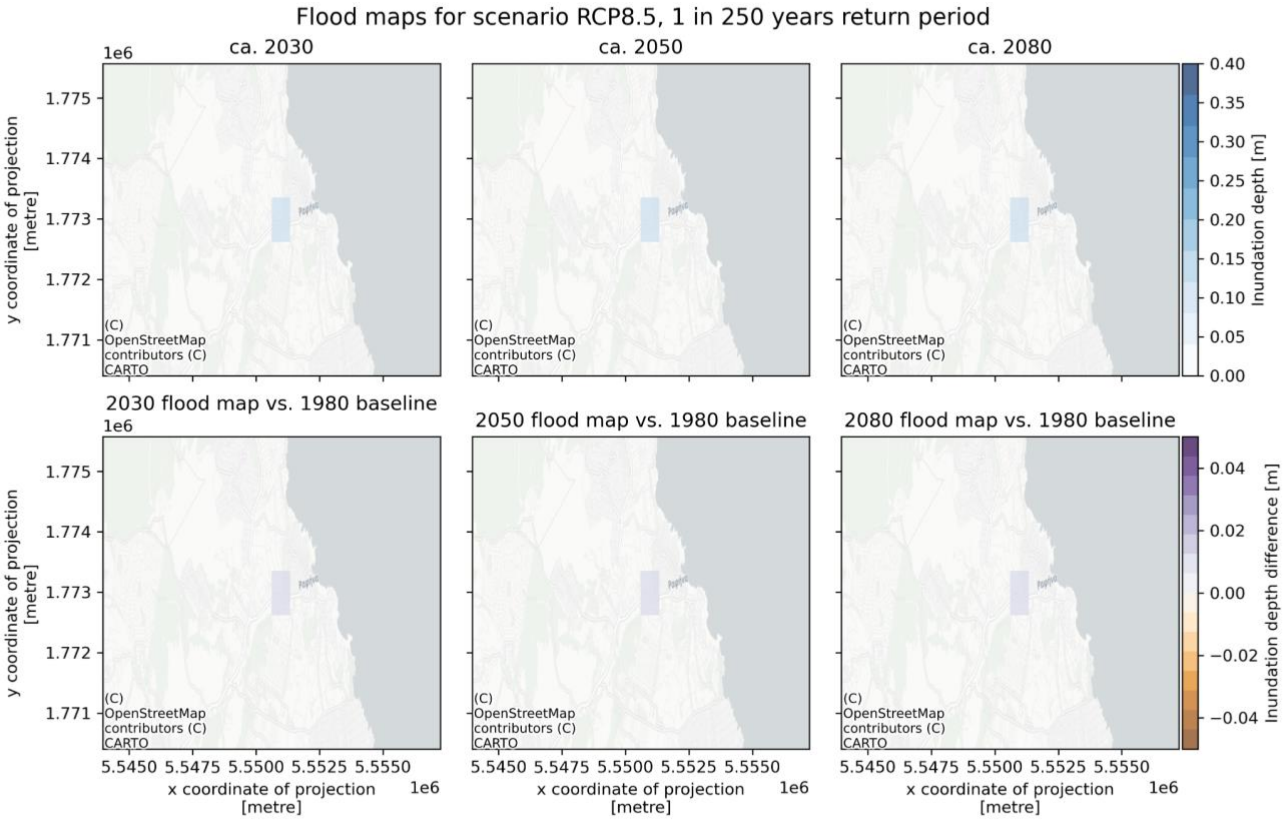

Fig. 3-3 Inundation depth (m) for climate scenario RCP8.5 for an event with a return period 250 years in 2030, 2050 and 2080 (upper row) and inundation depth difference (m) with respect to 1980 baseline.

The comparison maps of flood extents between 2018 and 2050, and between return periods, confirm that only the coastal zones demonstrate a measurable hazard increase, while river flood scenarios show virtually no change or development of risk, even under future climate extremes.

The failure of the CLIMAAX river flood methodology to replicate known flood extents in the Megalo Rema basin can be attributed to several critical limitations in both the input data and modeling assumptions.

First, the hazard maps are derived from global-scale hydraulic models that rely on coarse spatial resolution datasets, such as MERIT DEM or HydroSHEDS. These datasets often fail to accurately resolve narrow urban streams or flash-flood-prone gullies, especially those not included in major hydrological networks. As a result, key topographic features like the Megalo Rema channel are either smoothed out or even omitted, leading to unrealistic flow pathways and missing inundation zones.

Second, the methodology applies return-period-based riverine flood hazard layers that assume steady-state river overflow under generalized climate conditions. This approach does not account for pluvial and flash flood dynamics, which dominate the flood regime in Rafina. Past flood events have been driven by intense, short-duration rainfall, triggering overland flow, debris transport, and rapid inundation in highly urbanized catchments. These processes are not reflected in discharge-driven flood models.

Third, the LUISA land use layer, while useful for regional exposure studies, is too generalized for detailed urban flood risk assessments. Without calibration against local cadastral data or urban infrastructure layers, exposure estimates fail to reflect the real-world distribution of assets at risk, especially when hazard layers already show negligible inundation.

Lastly, the comparison with known flood extents from 2018 and observational boundaries confirms that the simulated hazard underrepresents actual flood behavior. Maps indicating the maximum observed flood extents show substantial overlap with the Megalo Rema stream, where the model predicts no activity, further reinforcing the discrepancy between model outputs and empirical evidence.

Consequently, the combined effect of insufficient river network representation, mismatch in flood typology, and generalized exposure modeling leads to a systematic underestimation of flood hazard and risk in the study area. The outputs presented are not consistent with the flood history or observed damages from past events and therefore do not provide a reliable risk assessment for decision-making or adaptation planning.

●.3.2.3 Coastal floods

This assessment evaluates the coastal flooding hazard for the Municipality of Rafina-Pikermi. The analysis follows the standardized methodology from the CLIMAAX Handbook for coastal flood hazard assessment, which uses historical extreme sea level statistics to estimate current hazard levels for specific return periods.

The objective is to establish a baseline understanding of the frequency and magnitude of extreme water levels, which is essential for coastal planning, flood protection design, and adaptation to future sea level rise (SLR).

The analysis is based on the CLIMAAX Coastal Flooding Workflow, which uses modeled water level time series (1979–2018) to estimate extreme sea levels using a Generalized Extreme Value (GEV) distribution. Key features of the methodology:

- Water level extremes are calculated relative to Mean Sea Level (MSL) around the midpoint of the dataset (approximately the year 2000).
- The values do not include future sea level rise, which must be added separately for future projections.
- The results are expressed as height above MSL for different return periods (i.e., how often a given extreme water level is statistically expected to occur).

Based on the closest station in the Copernicus Climate Data Store database, the estimated extreme water levels above MSL in the coasts of Rafina-Pikermi Municipality are:

- **0.40 meters which has been estimated for a 5-year Return Period event**
- **0.50 meters which has been estimated for a 100-year Return Period event**

The 5-year return period level of 0.4 m represents a moderate, but recurring, flood risk. It may affect low-lying infrastructure near the coastline, particularly under storm surge or high tide conditions.

The 100-year return period level of 0.5 m reflects a more extreme but less frequent event. While such events are rare, they carry a high impact potential, especially for critical assets such as ports, roads, and waterfront development in Rafina.

To further investigate the coastal flood potential, we processed the Global Flood Maps data via the Microsoft Planetary Computer, available for the present-day climate (ca. 2018) and future climate.

Using a Digital Elevation Model (MERIT DEM, 90 m resolution), flood extents and depths were modelled for:

- Return periods from 2 to 250 years
- Present-day (ca. 2018) and projected 2050 scenarios
- Water level scenarios adjusted for projected SLR in 2050

The coastal flooding analysis reveals spatially consistent inundation patterns along the low-lying waterfront, particularly in the vicinity of the southern part of Rafina port. These flood extents become more pronounced under the 2050 scenario and for higher return periods, with water depths reaching up to 1 meter. However, inundation remains confined to the immediate coastal fringe and does not extend inland toward major infrastructure or densely populated areas, affecting primarily the municipal car park and adjacent port facilities.

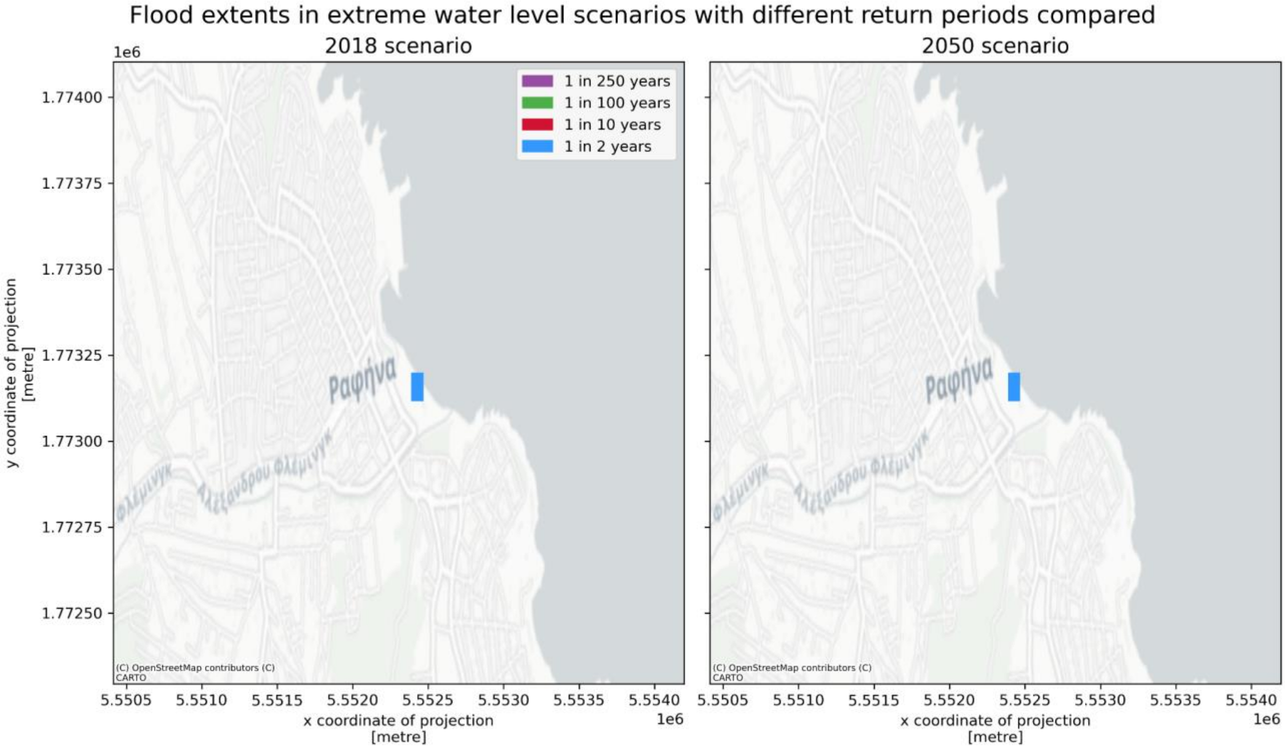

Fig.3-4 Flood extent in extreme water level in 2018 and 2050 scenarios with different return periods.

While inundation depths ranging only up to 1 meter along the coast, structural damage might remain limited for many buildings, even minor depths in critical zones (e.g., transportation routes, port facilities) could cause significant disruption.

Depths are generally deeper in 2050 compared to 2018 for the same return period (Fig. 3-5), supporting the expectation of worsening flood risk over time due to rising mean sea levels and potentially increased storm surge magnitudes.

The expected progression with increasing return period is visible in both 2018 and 2050:

- 1-in-2 years return period: Minimal but detectable inundation, representing frequent nuisance-level flooding.
- 1-in-10 years return period: Notably slightly higher depths, suggesting regular exposure of critical assets.
- 1-in-100 years return period: The maximum projected flood envelope, showing the broadest extent and greatest depth, especially in the 2050 case.

This confirms that coastal flood risk is sensitive both to the return period and future climate drivers, particularly SLR.

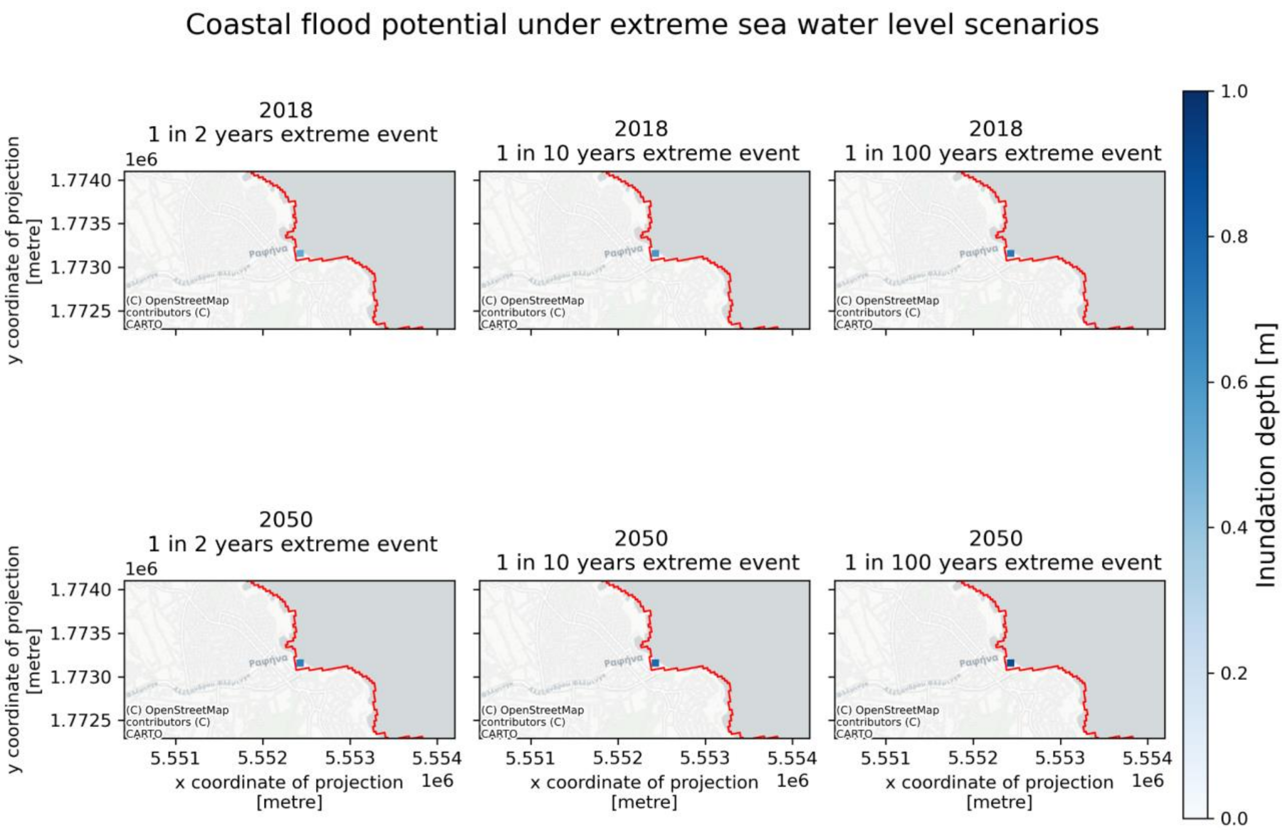

Fig. 3-5 Coastal flood potential under extreme sea-water level scenarios in present (2018) and future climate (2050).

●.3.2.4 Risk assessment

The risk assessment, which combines hazard outputs with exposure layers and economic damage models, shows minimal to moderate damage potential, with a few critical observations:

Building Exposure and Damage

The integration of LUISA land cover and OSM building datasets allowed estimation of direct economic damages (Fig. 3-6). However, due to the severely underrepresented flood hazard in riverine zones, the estimated flood damages are artificially low, with values under €0.05 million even for the most extreme events in 2050.

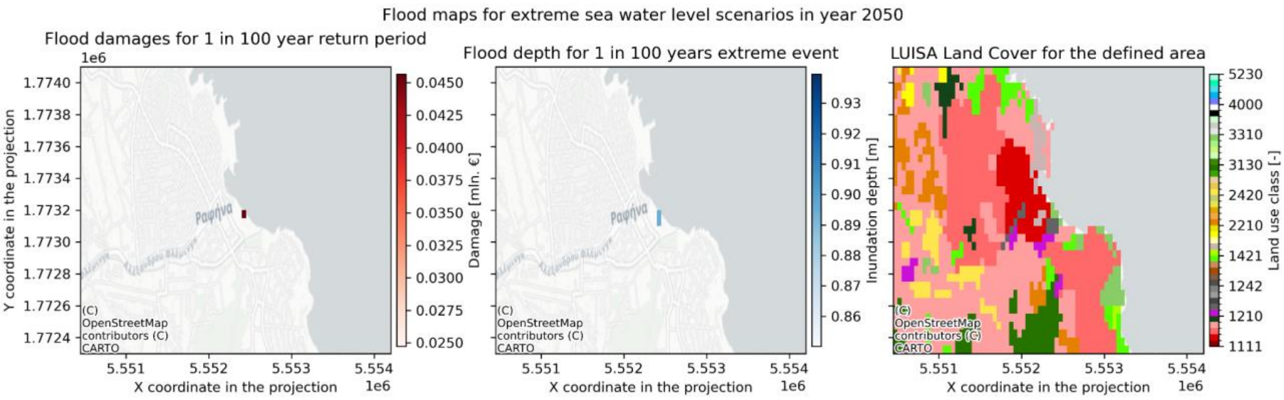

Fig. 3-6 Flood damage potential (mil Euros), Flood depth potential (m) for an event with a return period equal to 100 years, and the LUISA Land Cover in Rafina.

The damage-to-return period confirms that total direct damages remain under €0.6 million, even for a 1-in-500 year flood, with the mean expected annual damage (EAD) being approximately €0.03 million. This is inconsistent with known past damages in the Rafina urban core, reflecting an underestimation of both hazard and exposed asset values.

Damage for Mean depth (~0.4 m) and corresponding return period events in years (RP):

- RP=10: Total damage (€) = 163.266
- RP=50: Total damage (€) = 389.743
- RP=100: Total damage (€) = 459.507
- RP=500: Total damage (€) = 593.575

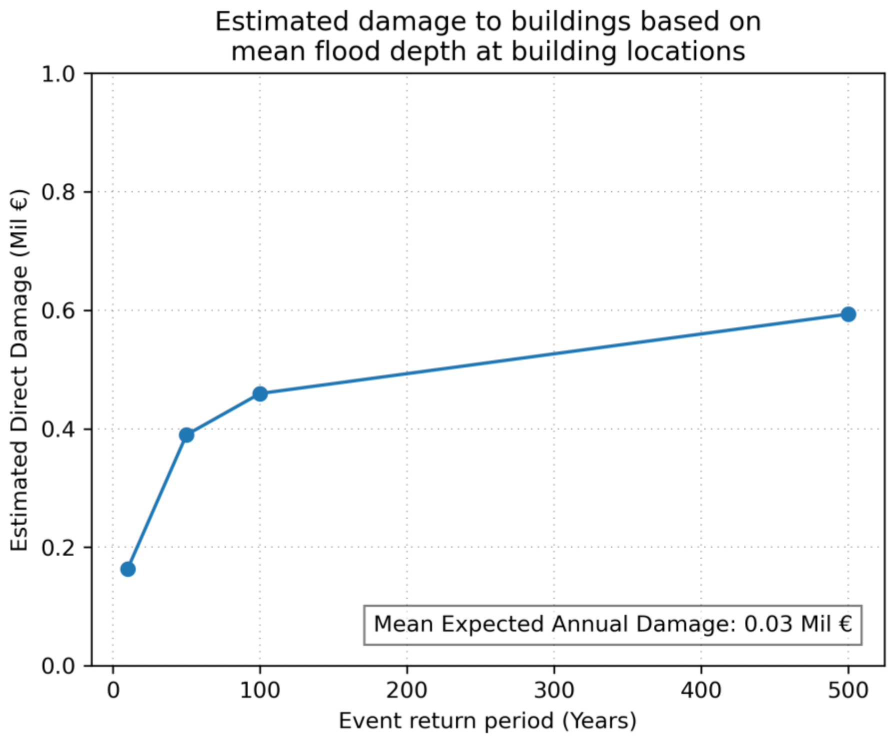

Fig. 3-7 Building damages vs return periods of the flood, for mean flood depth (~0.4 m)

Critical Infrastructure Risk

Assessment of critical infrastructure exposure to flooding (Fig. 3-8) (e.g., hospitals and fuel stations) for 10-year and 500-year return periods again shows no significant inundation across critical sites. This outcome appears reliable in the case of the local hospital, which is situated outside known flood-prone zones (Fig. 3-9) and at a considerable distance from the Megalo Rema stream. On the other hand, the fuel stations along the Megalo Rema stream are located in a low-lying urban valley, thus the result may fail to represent compound and fluvial hazard pathways for this critical infrastructure.

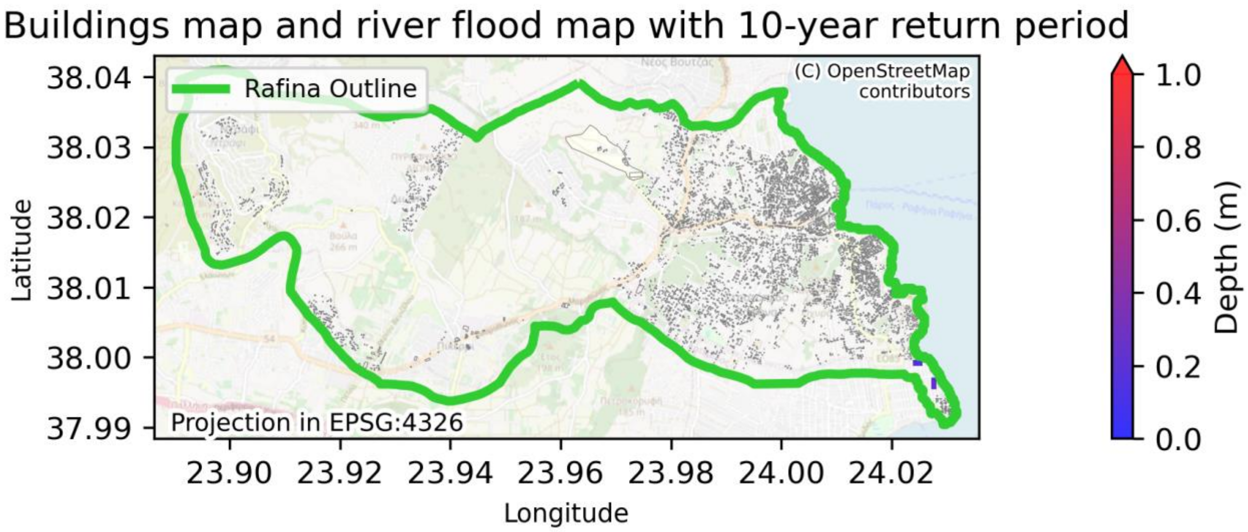

Fig. 3-8 Buildings and river flood depth (m) for an event with a return period of 10 years.

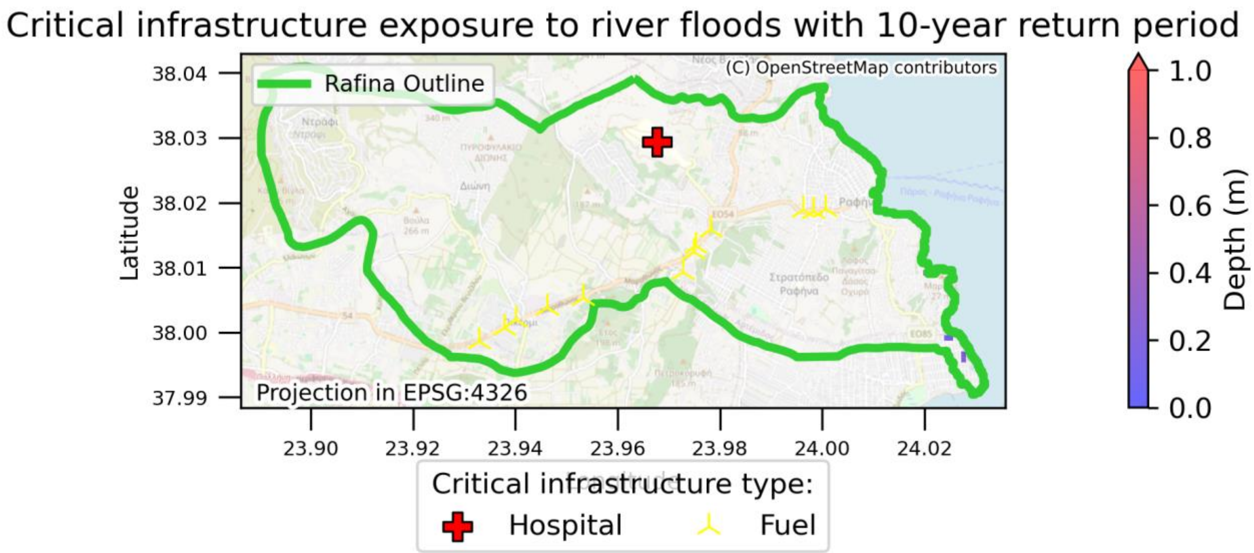

Fig 3-9 Critical infrastructure (hospital and fuel stations) and river flood depth (m) for an event with a return period of 10 years.

Population Exposure

The 2025 population raster overlaid with flood extents shows no significant population exposure due to the absence of simulated hazard in populated areas. This is a direct consequence of flawed hazard input layers and reinforces the importance of calibrating models with observed flood events.

- Expected annual population exposed: 3 people.
- Expected Annual Population Displaced: 0 people.

●.4 Preliminary Key Risk Assessment Findings

●.4.1 Severity

The heatwave risk assessment for the Municipality of Rafina-Pikermi reveals a clear and intensifying threat driven by rising temperatures, urban vulnerability, and uneven spatial exposure. The combination of high-resolution climate projections, satellite-derived land surface temperature (LST) data, and demographic vulnerability indicators demonstrates that the region is already experiencing and will continue to face increasing risks due to extreme heat events, especially under higher-emission climate scenarios.

The primary climate hazard identified in the region is the rising frequency, duration, and intensity of heatwaves, as defined by the EuroHEAT methodology, which considers both daytime and nighttime temperature thresholds. The combination of projected climate data (through 2050) and recent satellite observations (2021–2024) confirms that Rafina-Pikermi is highly exposed to intensifying thermal extremes, particularly in the inland urbanized areas.

Under the RCP 4.5 scenario, the number of heatwave days is expected to increase from a historical average of 4–5 days per year to approximately 17–18 days by 2050. However, under the RCP 8.5 scenario, this figure rises even more sharply to 23–24 days annually, reflecting a significantly more intense and prolonged thermal stress environment.

The divergence between the two emission pathways becomes especially apparent after 2030, with RCP 8.5 displaying a nonlinear and accelerated increase in heatwave events. This trajectory illustrates the growing risks associated with a high-emission, low-mitigation future, emphasizing the critical need for proactive climate action.

In particular, urban areas with high population density and limited natural cooling (e.g., vegetation or sea breeze) are especially vulnerable, as well as the Rafina port that hosts millions of tourists every year. Without targeted adaptation and mitigation strategies, these areas face severe public health impacts, strain on infrastructure, and diminished urban livability. The findings strongly support the urgency for local heatwave adaptation measures, improved urban planning, and prioritization of at-risk populations in municipal resilience planning.

The Rafina-Pikermi region is also exposed to two major but distinctly different flooding risks: riverine flash floods and coastal inundation. River flooding, particularly in the Megalo Rema basin, constitutes a major risk for the Rafina-Pikermi municipality due to its documented history of flash flood events. However, the CLIMAAX river flood hazard models fail to capture this reality. Across all return periods (10, 50, and 100 years for present-day; 250-year events for 2030, 2050, and 2080), the simulated river inundation remains minimal, restricted to narrow coastal segments and omitting the Megalo Rema channel entirely.

The failure to simulate known past flood events, such as the 2013 flash flood, suggests that the current methodology significantly underestimates flood hazard severity. Observational records and flood extents indicate widespread urban flooding in the Megalo Rema corridor, whereas the models indicate no inundation at all. This inconsistency is largely attributed to the limitations of global-scale DEMs and the omission of flash flood dynamics in the modeling approach. The assumption of steady-state, riverine overflow conditions does not reflect the rapid runoff, debris flow, and compound pluvial characteristics of actual events in Rafina. As such, while the real-world risk is high, the modeled severity appears artificially low.

This misrepresentation poses a serious limitation for risk-informed planning. It results in extremely low estimated economic damages—under €0.05 million even in extreme return period scenarios—and virtually no predicted population displacement or exposure, which contradicts past experience. Therefore, the true river flood risk remains high, particularly for densely urbanized, low-lying zones near Megalo Rema, even if not reflected in the model results.

Coastal flooding in Rafina is primarily concentrated in the low-lying areas surrounding the port, particularly near the municipality's southern waterfront. Modeled outputs, based on extreme sea level analysis and Digital Elevation Model processing, show measurable inundation for 1-in-2, 10, 100, and 250-year return periods for both 2018 and projected 2050 conditions. Inundation depth and spatial extent increase consistently with return period and future climate projections, with depths reaching up to 1 meter near the port area in 2050.

While the spatial impact of coastal flooding remains limited to the immediate fringe of the shoreline, the risk to critical infrastructure—particularly transportation routes, municipal car parks, and port facilities—is significant. Even minor inundation depths (<0.5 m) can result in substantial disruption to mobility, logistics, and emergency response, especially under high tide or storm surge conditions. Damage projections remain moderate overall, with maximum direct building damage not exceeding €0.6 million for 1-in-500 year events, but economic losses can become more impactful when considering indirect damages and operational disruptions.

Unlike the river flood analysis, the coastal flood models appear more credible in identifying existing and future hazard zones. The inclusion of projected sea level rise underlines the growing relevance of this hazard, especially by mid-century. However, the exposure assessment still underestimates potential disruption by omitting transport infrastructure vulnerabilities and compound effects such as simultaneous pluvial flooding or drainage overload.

●.4.2 Urgency

The Municipality of Rafina-Pikermi faces significant and immediate impacts from the two primary climate risks assessed: heatwaves and river and coastal flooding.

Heatwaves represent a clear and immediate threat, driven by steadily rising temperatures and increasing frequency and intensity of extreme heat events, especially under the RCP8.5 scenario. This risk requires urgent short-term actions, such as the immediate implementation of effective early-warning systems and the enhancement of existing cooling infrastructure in critical locations (e.g., healthcare facilities, elderly care homes, schools, and densely populated urban neighborhoods). Medium-term planning should prioritize widespread adoption of passive cooling techniques in building designs and urban planning strategies (e.g., expansion of green areas), aiming to significantly reduce urban heat stress and improve overall community resilience to extreme heat.

River and coastal flooding pose both immediate and evolving risks. Sudden-onset flooding events from intense rainfall episodes demand rapid response and preparedness in the short term. It is essential to urgently enhance existing civil protection measures, establish robust early-warning and evacuation systems, and secure critical infrastructure. In the medium to long term, comprehensive planning for structural interventions (such as improved drainage networks and flood barriers) combined with nature-based solutions (including restoration of natural floodplains and coastal ecosystems) is crucial. These measures not only address immediate vulnerabilities but also build enduring resilience against progressively worsening flood risks associated with climate change impacts like increased precipitation intensity and sea-level rise.

In conclusion, the urgency evaluation highlights that immediate, proactive action combined with strategic, forward-looking planning is essential. Addressing heatwaves requires rapid implementation of short-term interventions and subsequent medium-term infrastructural adaptations, while river and coastal flooding necessitate immediate preparedness enhancements coupled with sustained long-term investments in both structural and ecological solutions.

●.4.3 Capacity

The Municipality of Rafina-Pikermi currently possesses moderate capacity to manage climate-related risks, primarily driven by its active civil protection services and existing emergency management frameworks. These services have demonstrated a reasonable level of preparedness and responsiveness to face weather and climate risks. However, financial limitations stemming from broader economic challenges restrict the municipality's ability to execute larger-scale, strategic investments necessary for substantial infrastructure improvements, enhanced early-warning systems, and comprehensive long-term resilience planning.

In addition, constraints in human resources further limit the scope and speed of implementing adaptive and preventive measures. Despite these constraints, Rafina-Pikermi benefits from strong political support and an elevated level of community awareness regarding the urgency and necessity of climate adaptation and resilience. This political and societal acknowledgment creates a favorable environment for mobilizing future actions, provided there is effective strategic guidance and targeted resource allocation.

Significant opportunities lie ahead, particularly in fostering deeper community-based engagement and enhancing regional cooperation. By actively involving residents, local businesses, educational institutions, and non-governmental organizations in resilience planning and implementation, the municipality can significantly amplify its capacity . A critical step towards achieving this is the development and implementation of a carefully designed communication strategy. Such a strategy should effectively disseminate risk information, highlight community roles in climate action, and build broad-based support and cooperation.

Furthermore, regional collaboration with neighboring municipalities and alignment with national and European initiatives present substantial opportunities for accessing additional funding streams, sharing best practices, and coordinating broader adaptive responses. The present risk and vulnerability assessment is envisioned as a foundational element that will inform and drive strategic decision-making, planning, and resource prioritization, ultimately enhancing the municipality's resilience against future climatic risks.

●.5 Preliminary Monitoring and Evaluation

The first-phase of the climate risk assessment has provided significant insights into both the strengths and limitations of current methodologies and data availability for the Municipality of Rafina-Pikermi. Key lessons include recognizing the pressing need for enhanced local vulnerability datasets, particularly concerning demographic groups, housing conditions, infrastructure resilience, and precise socio-economic indicators. These data gaps have highlighted the importance of improving granularity to better identify and address the specific needs of the municipality's diverse communities.

During the initial assessment phase, METEOME encountered specific challenges related to integrating local spatial and observational data with broader EU-level hazard projections, emphasizing the necessity for standardized and interoperable datasets. Aligning these different scales of data posed practical difficulties, underscoring a critical need for streamlined processes and capacity-building within local administrative units.

Feedback from stakeholders has been encouraging and constructive, emphasizing a strong desire for active involvement in the next phases of the project, particularly regarding the co-design of tailored climate adaptation solutions. Stakeholders have expressed interest in developing localized adaptation strategies that consider specific vulnerabilities, community priorities, and existing capacities. Moving forward, engaging additional stakeholders such as healthcare providers, educational institutions, business representatives, and community groups will be vital to enrich the next iteration of the analysis, ensuring comprehensive and representative inputs.

To better understand and effectively mitigate identified risks, further resources and competencies will be required, including specialized training for municipal staff in the issue of early warning systems, climate data interpretation, vulnerability assessment methods, and the application of EU-level projections at the local scale. Additionally, fostering closer collaboration with research institutions and regional climate experts could greatly enhance the municipality's analytical capabilities, supporting a more detailed and actionable risk assessment process in the subsequent phases.

● Conclusions Phase 1- Climate risk assessment

Phase 1 of the CLIMAAX project in Rafina-Pikermi focused on a comprehensive climate risk assessment for key hazards expected to intensify under climate change: extreme heatwaves, river flooding, and coastal flooding. The assessment aimed to apply harmonized, open-source methodologies (as outlined in the CLIMAAX Handbook) for hazard modeling, exposure evaluation, and risk quantification. This phase represents a foundational effort to understand localized climate threats and build the evidence base for future adaptation planning.

The climate risk assessment produced several critical insights, but also revealed important methodological limitations, particularly for certain hazard types in this local context.

1. Extreme Heatwaves – Accurately Identified and Growing Threat

The analysis of heatwave risk, based on EuroHEAT thresholds and downscaled climate projections, was successful in characterizing current and future threats. Key findings include:

- A substantial increase in heatwave frequency is expected by 2050, rising from 4–5 annual heatwave days historically to 17–18 days under RCP4.5 and 23–24 days under RCP8.5.
- The divergence between emission scenarios after 2030 underscores the effectiveness of climate mitigation efforts in reducing public health risks.
- Satellite-derived Land Surface Temperature (LST) data validated the hazard, revealing inland urban hotspots with recurring summer peaks above 45 °C, particularly in July–August.
- The risk matrix approach showed that eastern-central Rafina, where high LST overlaps with high population vulnerability (e.g., elderly populations), is the most at-risk zone for heat-related impacts.

Overall, heatwave risk was accurately captured and confirmed as one of the most severe and increasing hazards for Rafina-Pikermi. This provides a robust basis for the development of targeted public health and urban heat adaptation strategies.

2. River Flooding – Critical Hazard Severely Underestimated

In contrast, the river flood risk assessment failed to reflect the historically documented flood behavior in the municipality. Despite using CLIMAAX's standardized workflows and data from JRC and Aqueduct Floods:

- The models did not simulate any flood hazard in the Megalo Rema stream, which has experienced major flash floods (e.g., 2013).
- All return periods and future climate scenarios showed negligible inundation, with maximum depths below 0.4–0.6 meters and no modeled impacts inland.
- Consequently, the estimated economic damages and population exposure were extremely low and inconsistent with known past impacts.

This failure stems from fundamental methodological limitations, including the use of coarse-resolution DEMs and the lack of representation of pluvial and flash flood dynamics typical of the local hydrology. As a result, the hazard and associated risk are severely underestimated, making the current outputs unreliable for local flood preparedness planning.

3. Coastal Flooding – Localized but Increasing Risk

The coastal flood hazard assessment was more effective in identifying areas at risk:

- Present-day and 2050 flood extents, derived from extreme sea level projections, show consistent inundation along the port and low-lying waterfront.
- Depths of up to 1 meter by 2050 are expected in high return period events (e.g., 1-in-100 or 1-in-250 years), posing risk to critical infrastructure such as municipal car parks, roads, and the port area.
- While the overall affected area is small, the potential disruption to mobility and infrastructure is significant, especially as sea level rise continues.

The damage estimates remain moderate due to the limited extent of inundation, but the results provide a credible warning of worsening flood risk due to rising sea levels.

The assessment successfully addressed:

- The integration of climate scenarios and health-related thresholds for heatwave hazard.
- Spatially resolved risk identification using exposure and vulnerability overlays.
- Initial screening of coastal flood risk under sea level rise scenarios.

However, key challenges remain unresolved:

- River flood modeling requires urgent refinement; current global datasets and assumptions do not reflect local flash flood behavior, particularly in the Megalo Rema basin.
- Exposure and damage models need calibration with local cadastral and infrastructure data for improved accuracy.
- Compound flood risks (e.g., pluvial + coastal) were not considered in this phase but may be relevant in urbanized coastal valleys.

Key Findings Summary

- Extreme heat is a growing and well-characterized hazard for Rafina-Pikermi, requiring immediate adaptation focus.
- River flood risk is critically underrepresented using standardized models and needs local hydrological calibration.
- Coastal flood risk is present and increasing, particularly near the port, although spatially confined.

This first phase establishes a valuable baseline but also highlights the need for local model refinement, improved data resolution, and integrated hazard approaches in future phases of climate resilience planning.

● Progress evaluation and contribution to future phases

Phase 1 of the CLIMAAX project has laid the analytical foundation for evidence-based climate adaptation planning in the Municipality of Rafina-Pikermi. The principal output of this phase—the Climate Risk Assessment (CRA)—provides a spatially explicit and hazard-specific evaluation of the municipality's exposure and vulnerability to extreme heatwaves, riverine flooding, and coastal flooding. This deliverable integrates hazard modeling, exposure assessment, and vulnerability analysis to inform both short-term risk management and long-term adaptation strategies. This assessment constitutes a critical input to the CLIMAAX methodological pathway and ensures alignment with the project's overarching objective of supporting harmonised climate risk management across Europe.

This deliverable directly contributes to the design and execution of the following project phases. In Phase 2, the CRA findings will support relevant adaptation strategies in collaboration with key stakeholders such as the Civil Protection Office, urban planning departments, and community representatives. In Phase 3, results will be synthesised into communication materials to support stakeholder engagement, raise public awareness, and promote institutional uptake of the proposed adaptation measures.

Importantly, the execution of Phase 1 has revealed both methodological strengths and operational gaps that will shape the implementation of future phases. The successful application of the CLIMAAX workflows for heatwave and coastal flood analysis provides a robust technical base for planning adaptation interventions (e.g. urban cooling zones, port infrastructure protection). Conversely, the limitations encountered in simulating riverine flash flood risk underscore the need for methodological refinement and local model calibration.

Phase 1 successfully met all of the defined Key Performance Indicators (KPIs) as outlined in the Individual Following Plan. The hazard assessments for heatwaves and coastal floods were implemented using the CLIMAAX Toolbox and integrated with demographic and land use datasets. Despite limitations in river flood modeling, the workflow was completed and documented, with explicit identification of performance gaps.

The mapping of vulnerable groups, land surface temperature anomalies, and infrastructure exposure contributed to the completion of composite risk assessments across all three hazard types. Each workflow was executed with scenario-based projections (RCP4.5 and RCP8.5), strengthening the forward-looking nature of the analysis.

Table 4-1 Overview key performance indicators

Key performance indicators	*Progress*
Heatwaves	Completed

Key performance indicators	*Progress*
River and Coastal Floods	Completed

Table 4-2 Overview milestones

Milestones	*Progress*
Hazard Layer Acquisition and Validation	Completed
Exposure and Vulnerability Mapping	Completed
Composite Risk Assessment	Completed
Gap Identification for Local Calibration	Completed

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